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CASE STUDY

The innovative double or triple dental abutment-implant: Case study with a 3-to-12-year follow-up

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ABSTRACT

Background: The aim of this case study is to present the rationality and scientific evidence of a new design for a double (DA) and triple (TA) dental abutment-implant with their specific new concept of biodynamic optimized peri-implant tissue (BOPiT).

Methods: The innovative design of these abutments with a paraboloid geometry was based on BOPiT, simultaneously involving the principles of mechanobiology, biotensegrity, and mechanotransduction. Thus, 37 consecutive individuals/43 cases rehabilitated with single dental implant using the innovative DA (n = 28) and TA (n = 15) on 43 implants were included in this case study. The DA and TA support 2 or 3 dental crowns on a single implant, respectively. Clinic and radiographic examinations were presented at T1 (loading after 4 months) and T2 [final examination with an average follow-up time of 7.2 years (>3 to 12 years)].

Results: At T2, mean scores for plaque index, peri-implant bleeding on probing, and peri-implant probing depth were low, depicting healthy peri-implant conditions. All radiographic images showed insignificant annual marginal bone loss (0.022 ± 0.05 mm) when compared to T1, reflecting great bone stability.

Conclusion: DA and TA, based on the BOPiT concept, represent an advantageous, simple and non-invasive mechanism for the longevity and healthy regulation of the peri-implant tissues.

KEYWORDS
alveolar bone, cellular, mechanotransduction, dental implants, dental implant-abutment design, implant prostheses and implants

INTRODUCTION

Researches to advance in the knowledge of implants and their respective abutments designs are a desirable goal, focusing on low surgical morbity, simplified technique, osseointegration stability and the longevity of the prosthesis-implant unit, as reported by numerous studies in implant dentistry.[1–5]

In this study, we present innovative dental abutment-implant with an elliptical and hyperbolic paraboloid geometry, a design based on integrated concepts of bone mechanotransduction,[6–8] biotensegrity,[7,9–12] and mechanobiology[6,8,12,13] referred as Biodynamic Optimized Peri-implant Tissue (BOPiT). It combines the mathematical and biophysical knowledge of vectors and load distribution, allowing the delivery of information to the peri-implant tissues in a differentiated dynamic way through the new double (DA) and triple (TA) abutments, being biologically active in their geometry.

All abutments currently available for prostheses have a cylindrical design, whether with internal, external or conical hexagon platforms and are welding dependent, in bridges or bars, with a minimum level of parallelism between the implants for seating and passivity for future multiple prosthesis.[14] It is important to emphasize that welding is critical and requires several steps to make a prosthesis, where each step can contribute to the occurrence of some type of distortion.[15]

The manner in which occlusal loads are transferred to the bone/implant interface via superstructures and implants is considered a crucial factor for the success of the treatment with dental implants, as its mechanical properties and structures interfere with the magnitude of occlusal forces.[16–19]

The new DA and TA abutments with paraboloid geometric design are totally curved and passive (without welds) and support two or three dental crowns respectively on a single osseointegrated implant, providing biomechanical advantages.

The objective of this study is to present the biomechanical informational effect of the paraboloid geometry of new dental abutment-implant, through a series of consecutive cases ($n = 43$) with the use of DA and TA through clinic exams and radiographic images at T1 (carrying the implants with the appropriate prostheses) and T2 (final examination) with a follow-up time of ≥3 to 12 years (average of 7.2 years).

MATERIALS AND METHODS

Conception and design of the DA and TA: scientific rationality

The new DA and TA feature a paraboloid geometric design along its entire length. The paraboloid is a mathematical equation that generates quadric surfaces of two types: elliptic and hyperbolic.[20] The elliptic paraboloid is shaped like an oval-shaped cup and can have a maximum or minimum point (an elliptic paraboloid opens upward—Figure 1A). The hyperbolic paraboloid, or hypar, is a doubly ruled surface (composed of multiple lines, whose union forms the surface itself), usually saddle-shaped. A hyperbolic paraboloid opens downward along one axis and upward along another axis[20] (Figure 1B).

The design of DA (elliptical paraboloid) and TA (hyperbolic paraboloid) allows high stiffness with reduced bending stresses and equalization of forces.[20] Additionally, TA hyperbolic paraboloid structures are the most complex and possess a unique combination of structural and architectural properties, resultant from its DA curvature, concave convex and suited to carry the in-plane shear forces and transmit uniform eccentric axial forces to the others members of the system. Vectorial loads are minimized, preventing the traditional axis of transverse coordinates that imply early bone loss in the implant abutment connection area. These designs represent the interaction that exists between all biological phenomena and mathematics.

The new abutments are multiple mechanical load organizers, and support 2 (DA) or 3 (TA) crowns on each abutment, with an innovative geometric design that is totally passive (no welds) (Figures 2 and 3).

Patients

This clinical investigation was designed as a pre-post case study and is reported in accordance with the PROCESS[21] and CARE.[22] All procedures performed in this study were in accordance with the ethical standards of the 1975 Declaration of Helsinki, revised in 2013. This case study has been independently evaluated by two different research boards. The first one was the Federal University of Minas Gerais Ethics Committee on research involving human (Approval Number: 5895732). In addition, it was registered at https://clinicaltrials.gov (register ID: NCT06127576) as an observational study.

Patients were recruited from a private clinic in the city of Belo Horizonte, Brazil, between September 2009 and January 2019.

The individuals included in the study were in good systemic health, non-diabetic and non-smokers. Prior to dental implant insertion surgeries, pre-surgical evaluation, detailed oral examination including complete periodontal examination, dental biofilm control and coronary polishing, as well as scaling and root planning and treatment of carious lesions (when necessary) were performed.

Since these new abutments break important paradigms in implant dentistry, such as passive multiple prostheses supported on a single implant with biomechanical benefits, we have cautiously chosen to perform only ~5 cases/year, aiming to reach a minimum follow-up time of 5 years. Additionally, patients who would require grafts to improve bone width or primarily the positioning/inclination of implants agreed to undergo implants using DA or TA in the absence of ideal conditions, but within the required limit for implants with a 4.0 mm diameter. Therefore, grafting procedures were not performed in all cases presented.

Thus, 50 consecutive cases in 44 individuals have been performed to date. From these 50 cases, 7 were excluded for the following reasons: 4 cases/4 individuals were lost due to lack of adherence to patient follow-up, 1 case/1 individual due to peri-implantitis with implant loss, and 2 cases/2 individuals due to porcelain fractures. Thus, the success rates of implants and technical complications in prostheses were 98.0% and 4.2%, respectively.

This consecutive case study comprises a sample of 37 individuals/43 cases (16 men and 21 women) with different extensions of edentulous spaces rehabilitated using DA ($n = 28$) and TA ($n = 15$) in 43 osseointegrated implants. All cases using DA and TA had occlusal function with their respective antagonistic pairs (natural, restored, or implanted teeth). Radiographic exams (analog or digital) are presented at T1 and at T2.

All implant insertion surgeries and prosthesis installations were performed by a single operator (L.S.C). The implants[*] (cylindrical implants with internal hexagon, without surface treatment, diameter: 4.0, length: 10 and 13 mm)

[*] Neodent, Grupo Straumann, Curitiba, Paraná, Brazil.

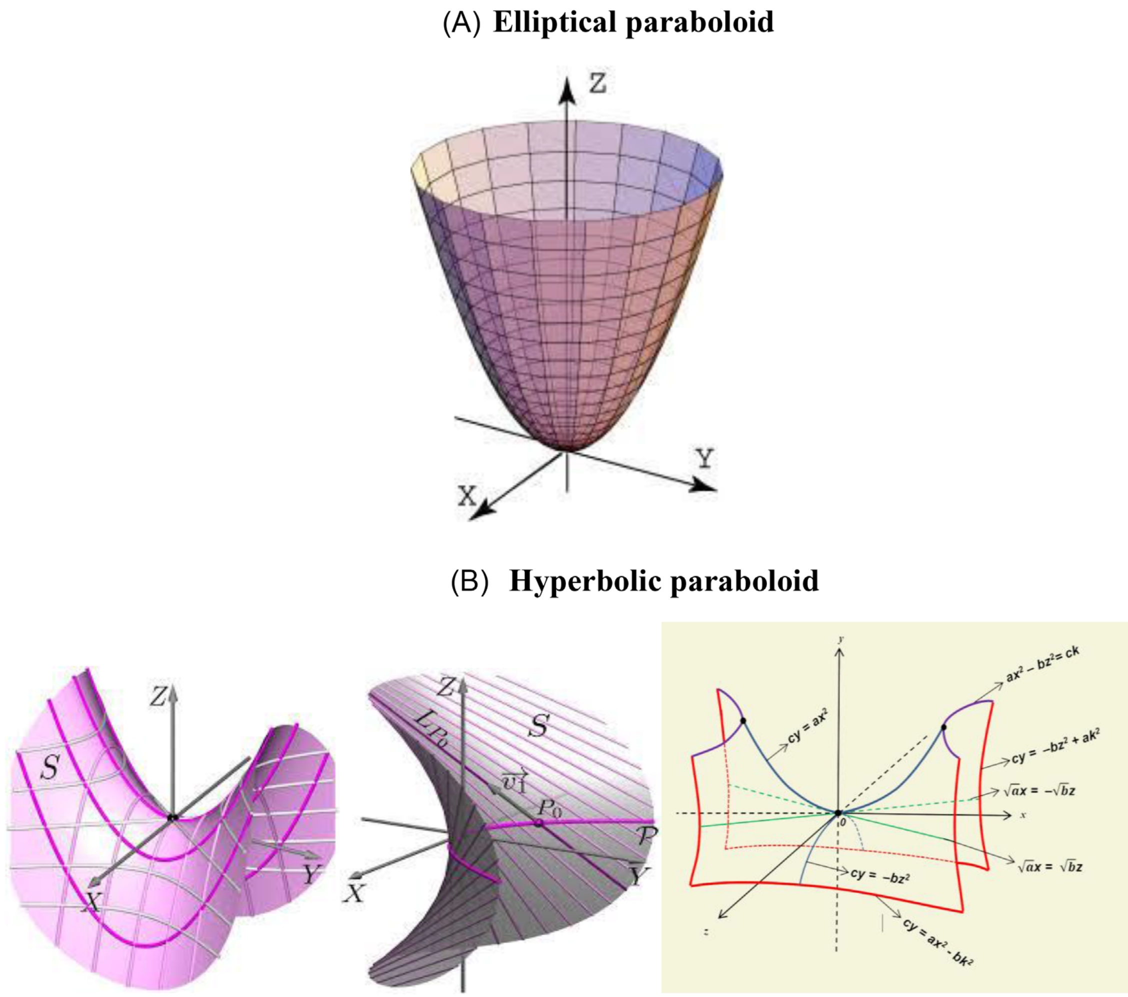


FIGURE 1 The surface of an elliptical (A) and hyperbolic (B) paraboloid: shape and equation of the paraboloid system.

were inserted according to a standardized protocol with the margin between machined and micro-rough surface at bone level. After 30 days of T1 and at T2, all patients received a radiographic and complete peri-implant clinical examination with recordings of plaque index [modified plaque index (PIi)[23] and peri-implant bleeding on probing (PiBP), height of keratinized tissue on implant (HKTi), peri-implant probing depth (PDi) measurements at four sites.[24]

Clinical and laboratorial procedures

(i) Selection of components for molding: analogs, transfers, and UCLA with metallic base in cobalt chromium compatible with the diameters and type of hexagon of the implant system[†] platforms installed and (ii) individualized drawing and sculpture are carried out on the selected UCLA according to the measurements and paraboloid surfaces of the DA (elliptical) and TA (hyperbolic). These personalized UCLA are subsequently cast resulting in a DA or TA cobalt chromium structure. All laboratorial procedures were performed in one single dental laboratory.

Three cases showing the clinical and laboratory stages with the use of DA and TA followed up for more than 10 years are presented in Figure 4.

Outcome measures

The primary outcome measure was the marginal bone loss (MBL) detected by radiographic examinations at T2. The mean values of PIi, PiBP, and PDi were determined to be the secondary outcomes.

Radiographs were taken at T1 and T2, due to the presence of analog and digital radiographs, the bone level was measured by the following manual method[25]: measurements were taken again with a negatoscope[‡] magnification 9×9 mm with an illuminator of varying intensity, using a graduated screen in millimeters (0.1 × 0.1 mm) and verified

[†] Neodent, Grupo Straumann, Curitiba, Paraná, Brazil.

[‡] Konex, Led Premium, São Paulo, São Paulo, Brazil.

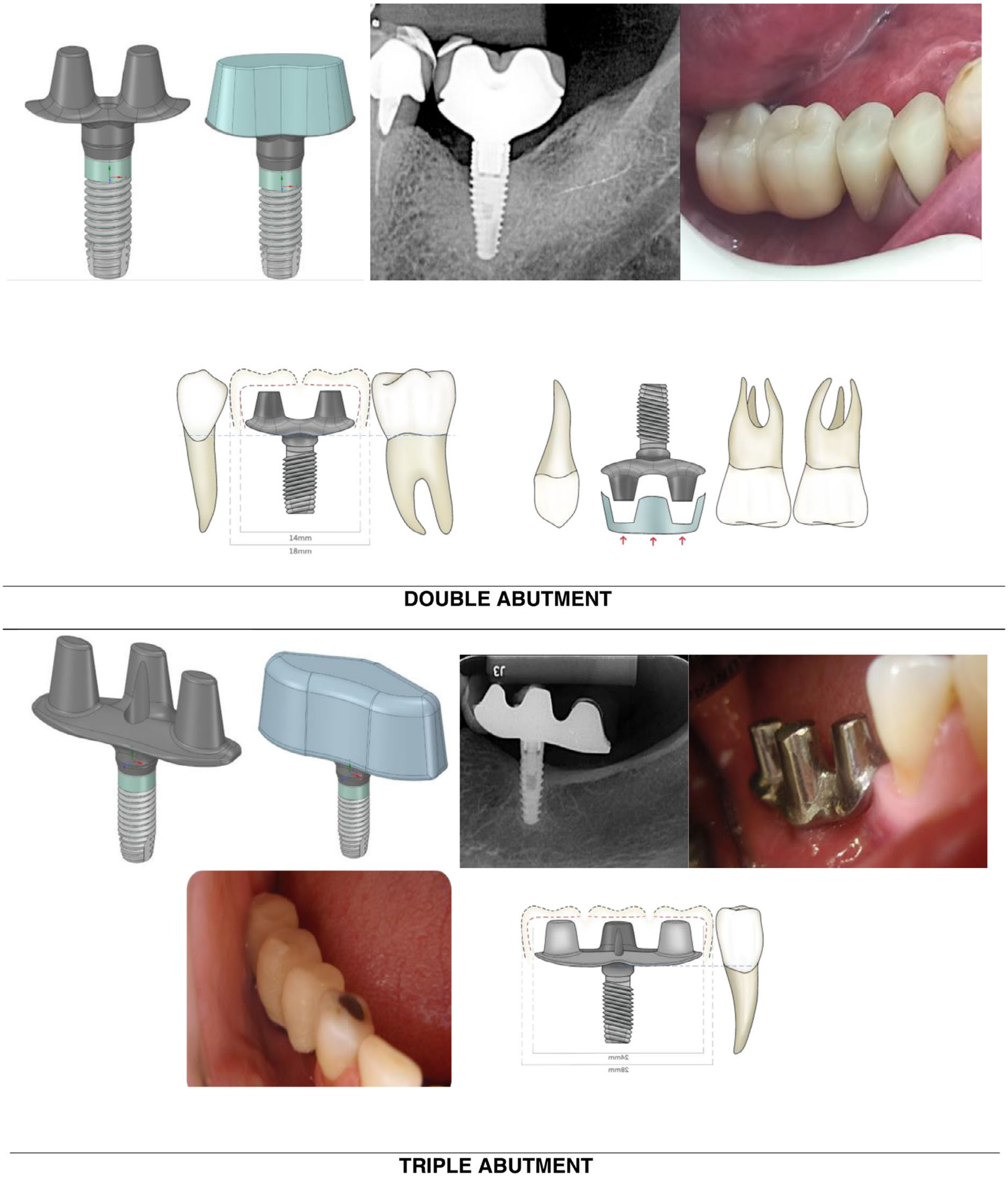


FIGURE 2 Double abutment (DA) and triple abutment (TA).

with a dry-tipped instrument[§]; and (3) the increase of the MBL was assessed in 0.1 mm intervals. Crestal bone changes were determined by measuring the distance from the reference line to the level of the margin of the crestal bone, both mesially and distally. The reference line on the radiograph was constructed by intersecting the uppermost top of the implant neck on the mesial and distal edge. MBL was presented as the highest value of either distal or mesial change between T1 and T2 after restoration placement for each implant.[26] The annual MBL was then calculated by the difference obtained at T1 and at the follow-up divided by the period between the two radiographs. All measurements were performed by a single trained examiner (F.O.C). Measurements of PDi and MBL were performed and repeated at T2 after 1 week in five randomly selected subjects. Results showed kappa values of >0.90 and >0.92, respectively, for

[§] Faber-Caspell, São Carlos, São Paulo, Brazil.

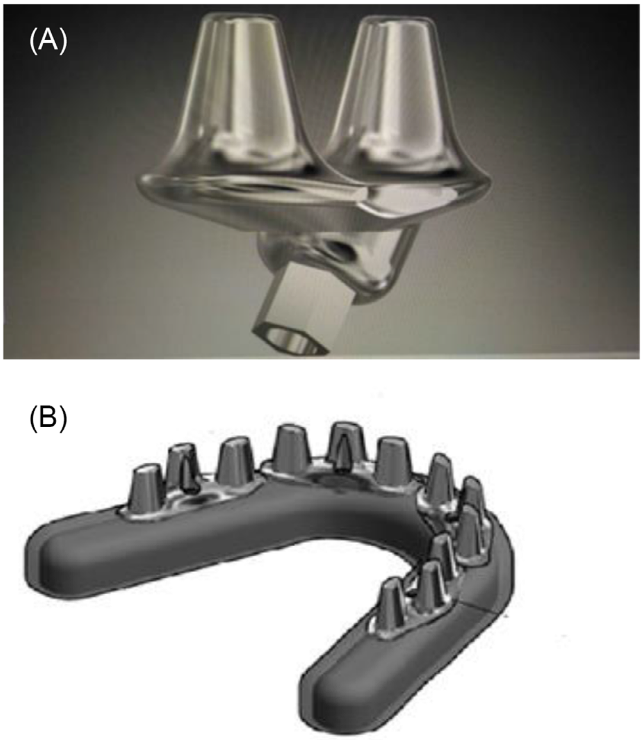


FIGURE 3 Inclined DA (A) and segmented multiple prosthesis TA (B). DA, Double abutment; TA, triple abutment.

dichotomized values greater or less than 3 mm for PDi and 0.2 mm for MBL).

Statistical analysis

Initially, we used implants as the unit of analysis. However, the sample of the case study included some individuals with two implants and, therefore, data may be correlated. Since sample size was small, as well as the number of individuals with two implants, a multilevel analysis would be jeopardized or underpowered. In order to evaluate the potential effect of this hierarchical structure and the extent to which the results were affected by this, a sensitivity analysis was performed. All study comparisons regarding PPDi, MBL, HKTi, and PiBP were also performed in two other ways. In individuals with two implants were used: (1) a mean implant value per individual; (2) the value from a randomly chosen implant. Since data from these analyses were consistent with those from the primary analysis and the changes on *p*-values were minimal showing little or no influence of correlated data, we kept the primary analysis (implants as the unit of analysis).

Differences among clinical variables and evaluation times were determined through the *t*-Student or McNemar tests, when appropriate. All tests were performed using statistical software.[**]

[**] Statistical Package for Social Sciences, 17.0 – SPSS Inc., Chicago, IL, USA.

RESULTS

Table 1 presents the clinical characteristics of interest of the participants at T1 and T2. A total of 37 individuals (16 men and 21 women) and 43 implants using DA ($n = 28$ cases) and TA ($n = 15$ cases) were included in this case study. The cases were almost equally located in the upper and lower jaws, being 11.6% in the anterior region and 88.4% in the posterior region. The average age at T1 (implant loading with the appropriate metalloceramic prosthesis) was of 50.7 (±5.2) years and at T2 (final examination), it was of 64.3 (±8.5) years.

The total average follow-up time was of ~7.2 years (± 0.9; ≥ 3–12 years). Cases were divided into three groups: (A) ≥10 years [n = 17 cases; DA = 12; TA = 5; 10.8 ± 1.2 years (Figure 5)]; (B) ≥ 5 to < 10 years (n = 16 cases; DA = 11; TA = 5; mean: 7.1 ± 0.9 years); and (C) ≥ 3 years of follow-up (n = 10 cases; DA = 5; TA = 5; mean: 3.2 ± 0.2 years). The patients showed good compliance and regularity in maintenance visits (Table 1).

The peri-implant clinical parameters of interest are shown in Table 1. From T1 to T2, all peri-implant clinical parameters were consistent with peri-implant health without significant differences in follow-up times for PIi (p = 0.229), PDi (p = 0.459), and %PiBP (p = 0.058), but significant increase in HKTi (p = 0.003).

The mean annual MBL was of 0.022 ± 0.05 mm, in total with 0.043 ± 0.07 mm in the maxilla and 0.015 ± 0.06 mm in the mandible (p = 0.001). Regarding study groups, the annual MBL was: group A = 0.028 ± 0.04; group B = 0.025 ± 0.06; and group C = 0.015 ± 0.03, with no significant differences among groups (p = 0.094) (Table 1). There were also no significant differences in the annual MBL when comparing DA (0.025 ± 0.04) and TA (0.019 ± 0.06) (p = 0.081).

Figure 5 shows a radiographic panel, with T1 and T2 radiographic examinations for group A (≥ 10 years; numbers of implants = 17; DA = 12 and TA = 15 cases). At T2, all radiographic images notably showed minimum MBL, no angular defects or bone craters when compared to T1, reflecting good bone qualities in relation to cortical thickness, trabecular volume and a high rate of mineralization, as well as the absence of clinical signs of inflammation in the peri-implant tissues.

DISCUSSION

The clinical cases presented through clinical examination and radiographic images demonstrated longitudinal (at T2) peri-implant tissue health (PDi ≤ 4 mm, absence of PiBP and SU) and bone homeostasis (very low annual MBL—0.022 ± 0.05 mm) when using the new abutments in different clinical situations with a follow-up of up to 12 years. Thus, all cases presented health and stability of the implant-prosthesis according to definition proposed by Araújo and Lindhe[27] and Renvert et al.[28]

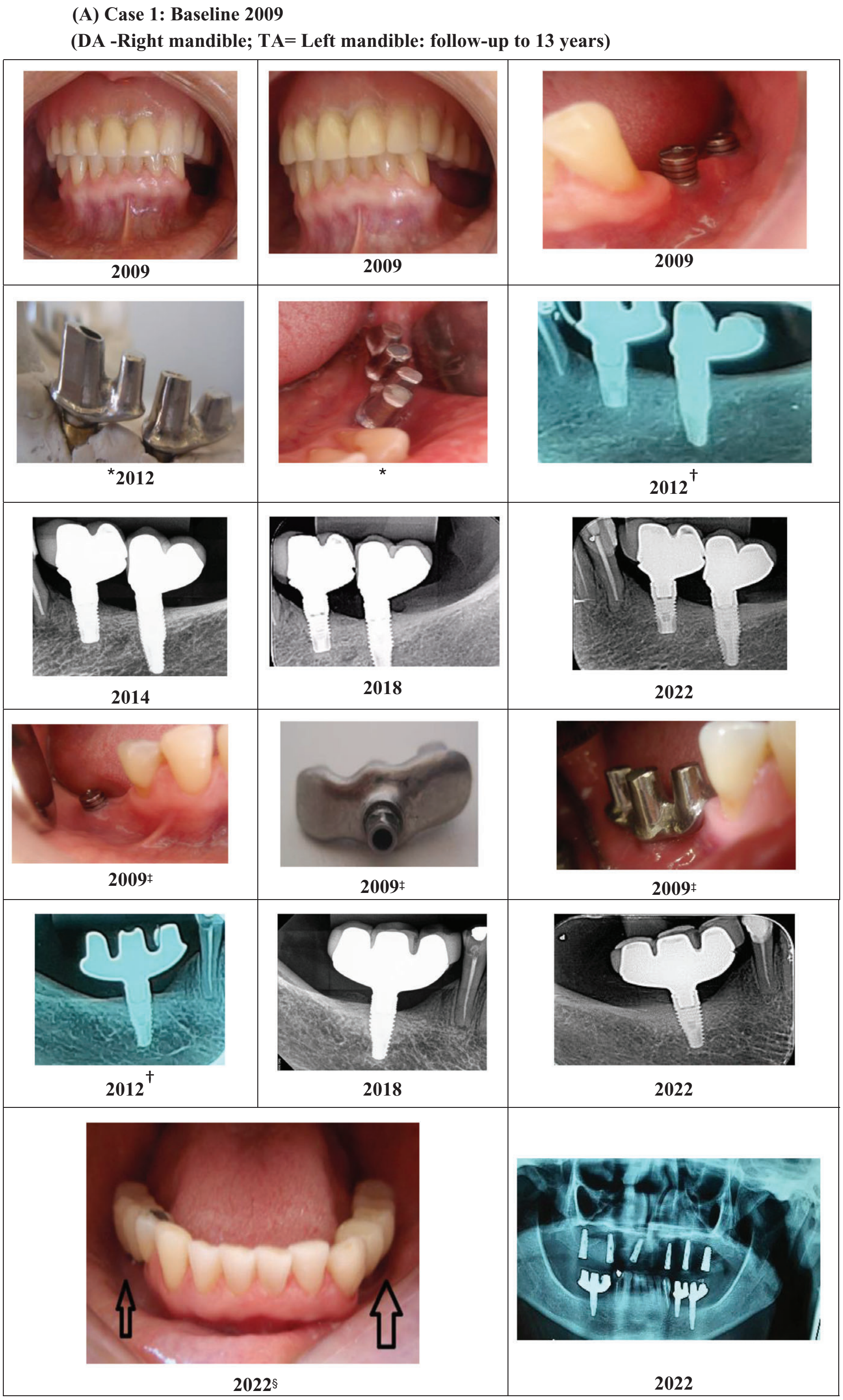


FIGURE 4 DA and TA clinical cases. DA, Double abutment; TA, triple abutment.

*The choice of the abutment is based on the dimensions to be rehabilitated and the height of the intramucosal profile according to the implant insertion (intraosseous or at bone level). After installing the abutments, there is no need for manipulation in the transmucosal region, and impressions can be taken in the mouth.

†X-rays should be taken without the dental crown to check abutment adaptation and peri-implantar condition. From 2012 to 2014, an acrylic resin crown remained in function for personal reasons.

‡Edentulus área with single dental implant; sequence of using the TA (basal and lateral view).

§Occlusal view of ceramic prostheses (small arrow indicating the use of DA on the right side of the mandible and large arrow indicating TA on the left side) after 13 years of function.

|| Edentulous area approximately 15 millimeters in length mesiodistally with an uncovered dental implant; sequence of using the DA (lateral and occlusal view); prosthesis with 2 elements in porcelain.

¶Edentulous area approximately 20 millimeters in length mesiodistally with an uncovered dental implant; sequence of using the TA (basal and lateral view); prosthesis with 3 elements in porcelain.

#Removal of the prosthesis to examine peri-implant conditions after 1 year of function.

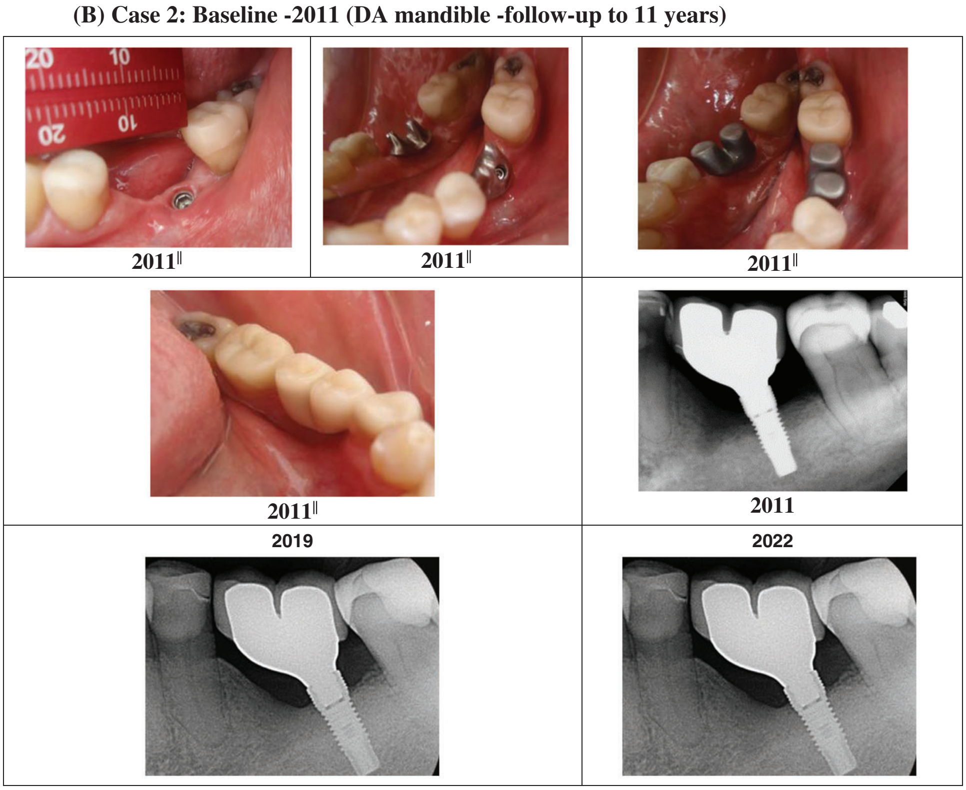


FIGURE 4 Continued

The mean annual MBL was 0.022 ± 0.05 mm in total with 0.043 ± 0.07 mm in the maxilla and 0.015 ± 0.06 mm in the mandible. These rates are known as the minimum acceptable and compatible with peri-implant health in different prospective studies.[26,29,30]

The geometric design,[20] together with the established concept of BOPiT, revealed a surprising optimization of peri-implant tissue responses. The quadric surfaces of these new abutments allow an instantaneous vectorial distribution of the received masticatory loads in the implant-abutment connection area with a shift in the center of gravity of the assembly. Consequently, a primary biophysical dissipation of the stresses in the abutment occurs before they reach the attachment site of the implant-abutment connections. Therefore, these forces are redistributed to the alveolar bone.

DA and TA provide the following positive conditions: (i) reduced stress concentration at the implant seating platform and screw; (ii) rehabilitation of extension areas of 2–3 dental elements with a single implant; (iii) rehabilitations in the presence of inclined implants or without minimal parallelism; (iv) elimination of the undesirable "cantilever" prostheses type effect; (vii) no welds with total passivity; and the ease of hygiene (the parabolic emergence prophylactic profile of these abutments allows the use of common dental floss due to the segmented arrangements supported on a single implant).

According to Hämmerle et al.,[31] the concept of multiunit fixed reconstructions with cantilevers can be recommended as a viable treatment option rendering high survival rates for reconstructions and implants. For single-implant reconstructions with cantilevers, the data available are promising but so scarce that the procedure cannot be recommended for routine clinical use.

In this context, the use of DA and mainly TA represents a great advance when compared to traditional cantilevers in dental implants.

The use of new abutments DA and TA rehabilitate edentulous spaces of 10–20 mm in length (Figure 4B) and allow for changes in focus in the anatomical (bone quality) and operative (insertion orientation) approach, enabling their prosthetic versatility. It is true that the variability of clinical situations of tooth loss bring the need for prosthetics as of the systems. However, this correspondence does not always occur in practice.[32] The most common problems resulting from these clinical situations are biological complications of the peri-implant soft tissues, bone loss and mechanical complications, such as screw loosening or fractures of implants or prostheses.[32–34]

Particularly, mechanical complications in dental implants are widely reported in the literature and involve a plurality of etiologies, risk factors and are still inconclusive.[33] When using DA and TA (porcelain fused to metal in cobalt–chromium) in simple cylindrical implants, internal hexagon and without surface treatment, the absence of special characteristics in implants did not appear to affect outcomes, that is, success rates appear to be related to the equalization of forces under the pillars.

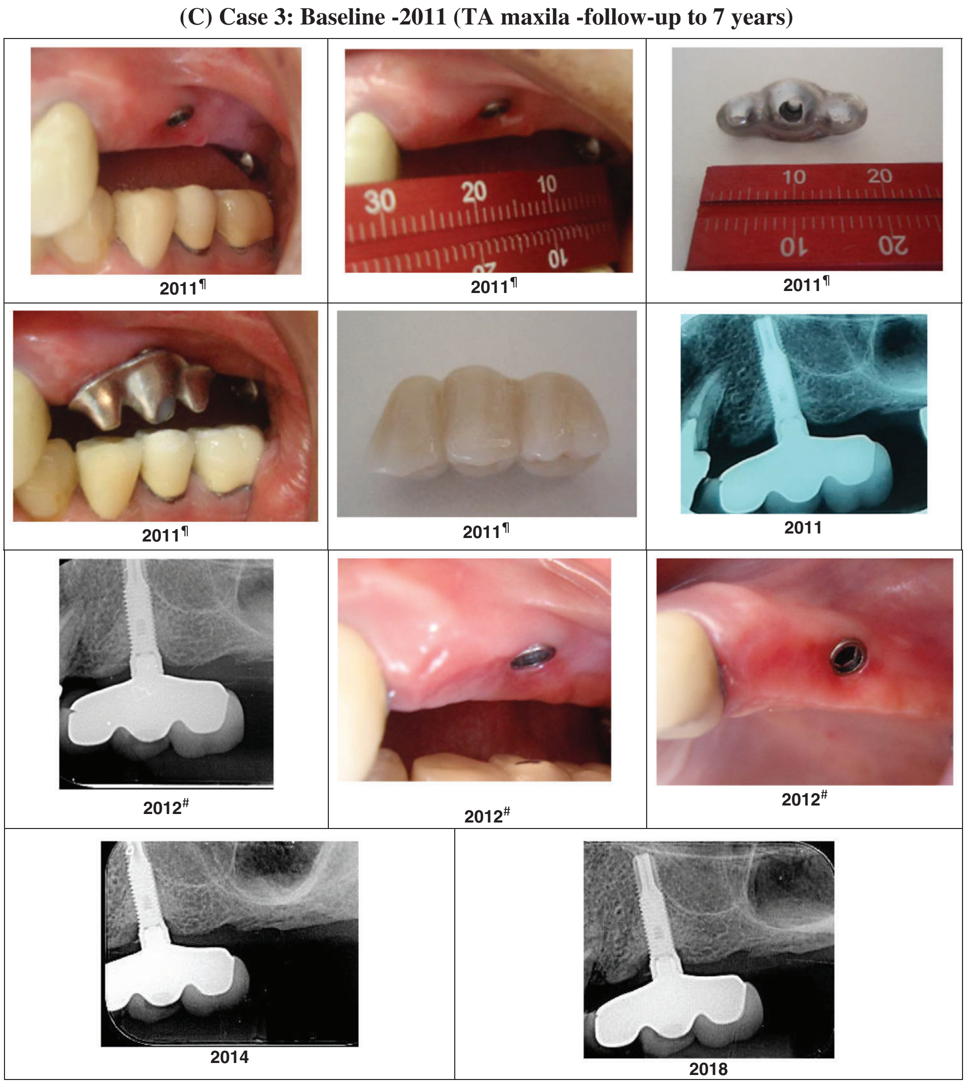


FIGURE 4 Continued

Corroborating our findings of a low rate of technical complications in prostheses (porcelain-fused-to-metal: ~96%), a systematic review and meta-analysis conducted by Pjetersson et al.[35] demonstrated that implant-supported single crowns, both metallic and ceramic abutments with internal and external connections, exhibited high survival rates. Furthermore, implant-supported fixed bridges with metal pillars, featuring internal and external connections, also showed high survival rates (ranging from 95.7% to 97.6%).

Regarding the occlusion in prostheses with DA and TA, they adhere to the principles of occlusion in implant dentistry,[36] particularly with the absence of contact in light and moderate occlusion (30 μm relief), and with slight centralized contacts in maximum intensity occlusion.

The main limitation of this present research relates to the study design, being it a case study based on consecutive patients and lack of standardization of radiographic exams from T1 to T2. The second limitation concerns the need for the abutments to be customized according to the proper inclinations and prosthetic spaces, respecting the described geometry. Third, there are difficulties in obtaining the aesthetic adaptation of the prostheses. However, these limitations are currently mitigated by modern laboratory resources and the use of software for design configurations.

Moreover, there is a clear need for future prospective studies using these abutments in comparison with traditional abutments under similar peri-operative conditions in different study designs. However, this study signals an important starting point of biomechanical innovation with the use of the new abutments in their specific distribution of loads in implant dentistry rehabilitation in a segmented and simplified form.

CONCLUSION

This consecutive case study with a follow-up of up to 12 years revealed that the use of DA and TA, based on the

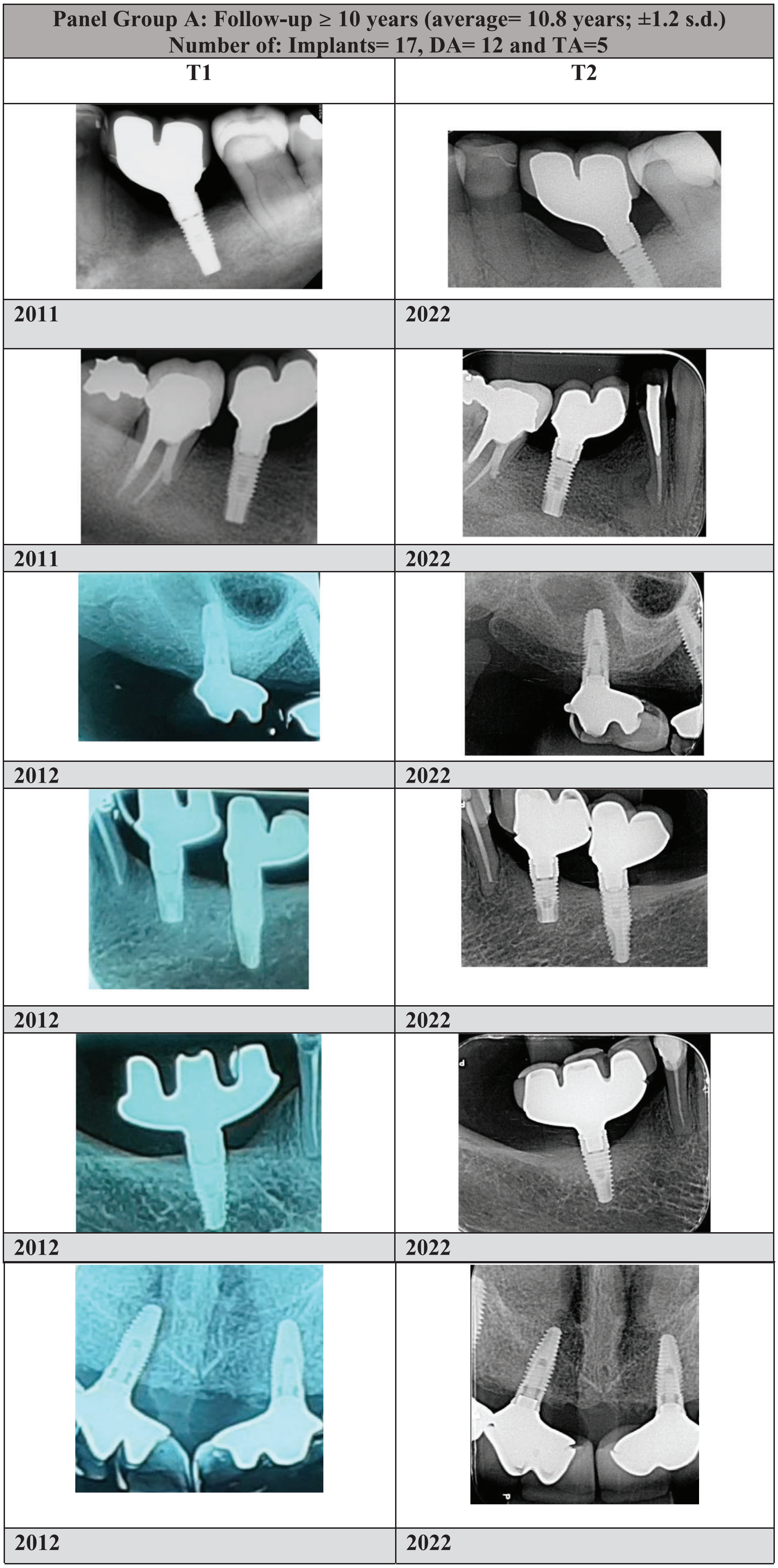
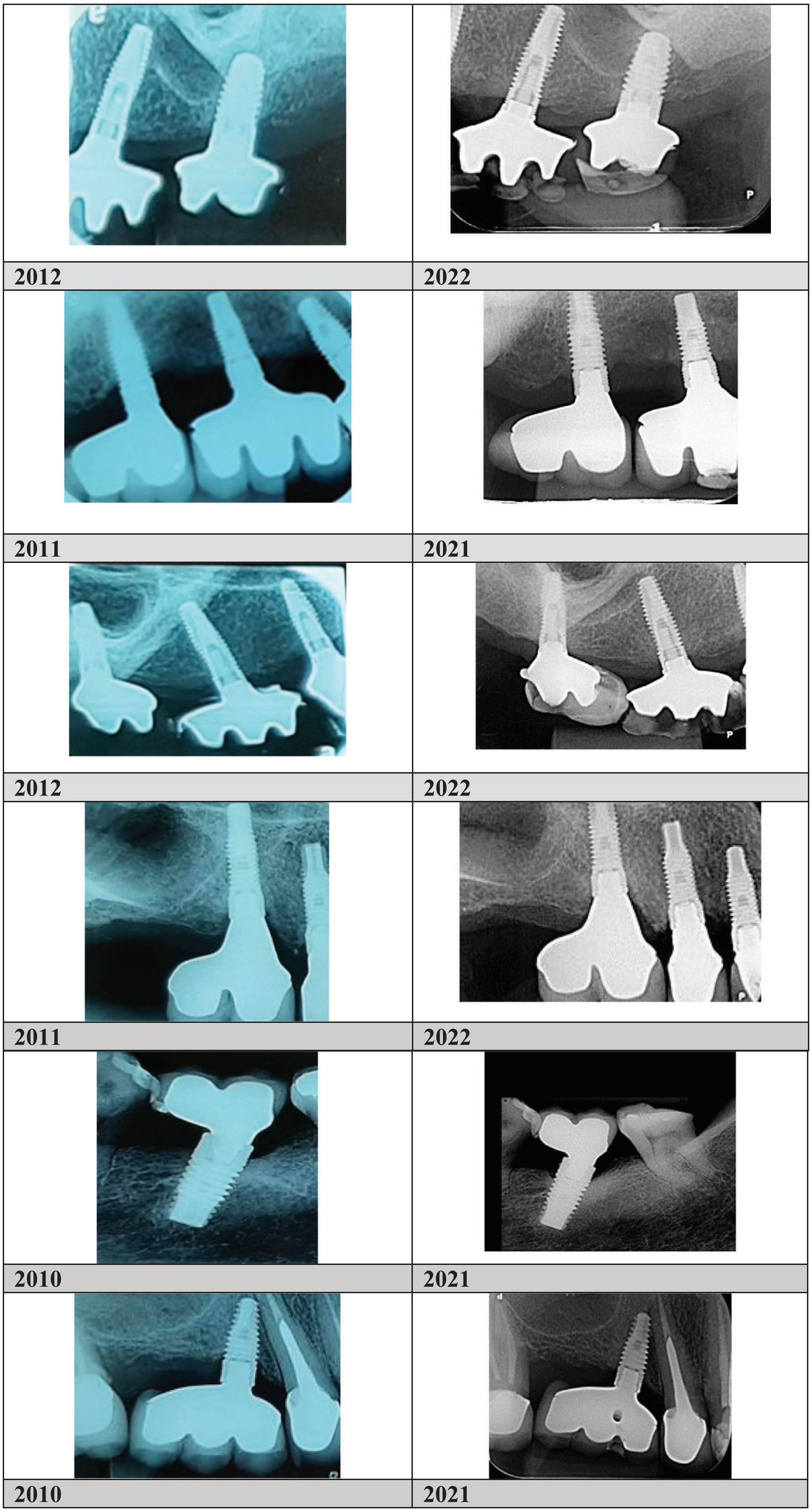


FIGURE 5 Initial (T1) and final (T2) radiographic panels using the DA and TA in follow-up Group A (≥ 10 years). DA, Double abutment; TA, triple abutment.



T1= Radiographic examination after loading the implants with their respective prostheses using DA and TA; T2=Final radiographic examination.

FIGURE 5 Continued

TABLE 1 Clinical characteristics of the studied patients.

Patients (*n*)	37 (21 women; 16 men)
Age	T1 = 50.7 (±5.2); T2 = 64.3 (±8.5)
Implants/cases (*n*)	43
DA (*n*)	28 (65.1%)
TA (*n*)	15 (34.9%)
Segment of the arch (*n*)	
Anterior	5 (11.6%)
Posterior	38 (88.4%)
Arch (*n*)	
Maxilla	21 (49.1%)
Mandible	22 (51.1%)
Follow-up time at T2 (years; mean; s.d.)	7.2 (± 0.9)
Group A ($n = 17$)	10.8 (± 1.2)
Group B ($n = 16$)	7.1(± 0.9)
Group C ($n = 10$)	3.2 (± 0.2)
Number of maintenance visits at T2 (years; mean; s.d.)	
Group A ($n = 17$)	8.7 (±1.8)
Group B ($n = 16$)	6.5 (±1.3)
Group C ($n = 10$)	4.7 (±0.6)
Pli (mean values; s.d.)	T1 = 1.11 (± 0.39); T2 = 1.37 ± (0.49); *$p = 0.229$
PPDi (mm; mean values; s.d.)	T1 = 2.3 (±0.82); T2 = 3.0 (±0.61); *$p = 0.459$
PiBP (mean values; s.d.)	T1 = 0.70 (± 0.31); T2 = 0.85 ± (0.42); *$p = 0.058$
HKTi (%)	
0–1 mm	T1 = 4%.6 ($n = 2$); T2 = 6% ($n = 3$)
> 1–2 mm	T1 = 30.2% ($n = 13$); T2 = 18% ($n = 8$)
> 2 mm	T1 = 65.2% ($n = 28$); T2 = 76% ($n = 32$) $^{\dagger}p = 0.003$
MBL (mean annual values—s.d.)	
Total (T2)	0.022 ± 0.05
Maxilla	0.043 ± 0.07
Mandible	0.015 ± 0.06 ($p^{\dagger} = 0.001$)
Group A	0.028 ± 0.04
Group B	0.025 ± 0.06
Group C	0.015 ± 0.03 ($p^{\dagger} = 0.094$)

Abbreviations: Pli, Modified plaque index; PiBP, peri-implant bleeding on probing; HKTi, height of keratinized tissue on implant; PPDi, peri-implant probing depth; MBL, marginal bone loss. Group A: ≥ 10 years; Group B: ≥ 5 years, and Group C: ≥ 3 years. *Student *t*-test for dependent samples (mean ± s.d.); †McNemar test; s.d., standard deviation.

BOPiT concept, represent an advantageous, simple and non-invasive mechanism for the healthy regulation of the peri-implant tissues. This study represents a test of the principle about use of single implants with new abutments for multiple prostheses that can be considered a physiological, innovative, and integrated biodynamic alternative in rehabilitations with lower morbidity, passivity, ease of cleaning and could provide a useful prosthetic solution in several cases.

AUTHOR CONTRIBUTIONS

All implant insertion surgeries and prosthesis installations were performed by Luciana Silva Colepícolo. Fernando Oliveira Costa provided scientific support. Luciana Silva Colepícolo and Fernando Oliveira Costa made substantial contributions to the conception, protocols and development of this study. All authors Luciana Silva Colepícolo, Maria Auxiliadora Mourão Martinez, Andrea Augusto Rodrigues, Leonardo Silveira Baeta, and Fernando Oliveira Costa were involved in data interpretation, drafting the manuscript and revising it critically and have given final approval of the version to be published.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

FUNDING INFORMATION

The study was self-funded by the authors and their institutions.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available upon reasonable request to the corresponding author.

PATENTS

DA and TA are protected by the following patents: (PI BR 0505827-9; PI BR 0800298-3, Brazil), United States (United States 9039416; 11,701,206 and United States/Canadian 2,630,592).

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